Knowledge Transfer Workshop Agenda

Time	Section	Person
1:00 1:10	Welcome and Opening Remarks	Niagara Region
1:10 1:20	Brief Introduction to Climate Modeling	TRCA
1:20 1:50	Climate Projections: Methods/Results	TRCA
1:50 2:50	Discussion/Questions	All
2:50	Closing Remarks	TRCA/Niagara Region

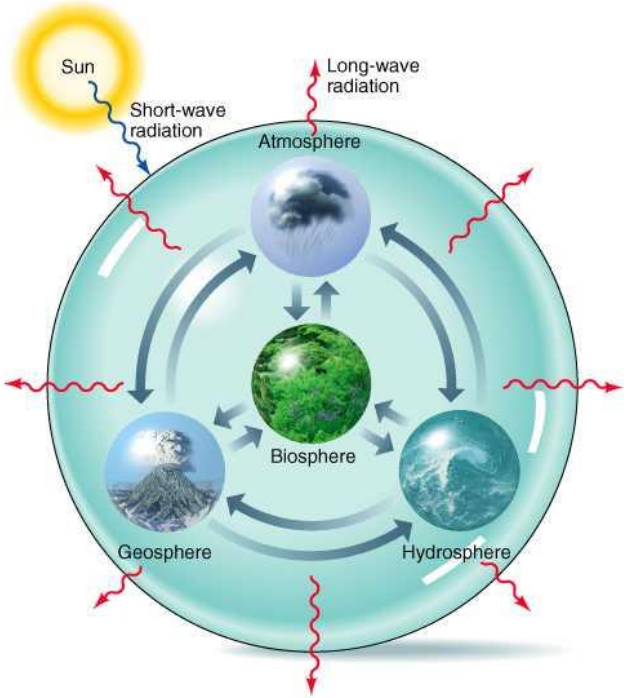
Knowledge Transfer Workshop:
Climate Change Modelling for Niagara Region

Presented by: Yuestas David and Lubna Seal

February 16, 2022

Toronto and Region Conservation Authority

Introduction to Climate Modeling



Introduction to Climate Modeling

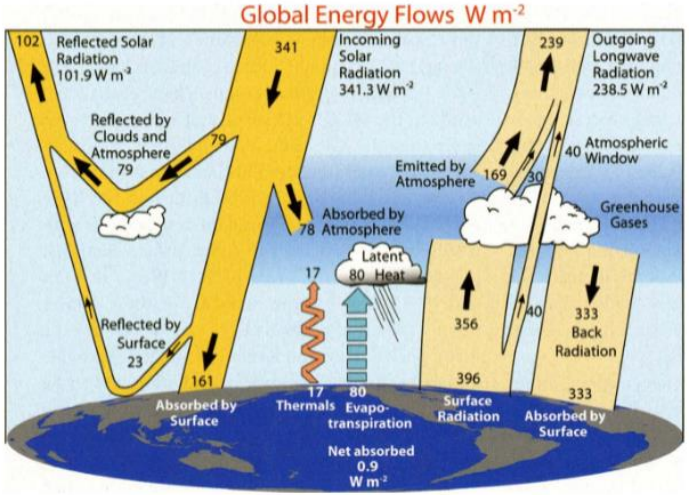
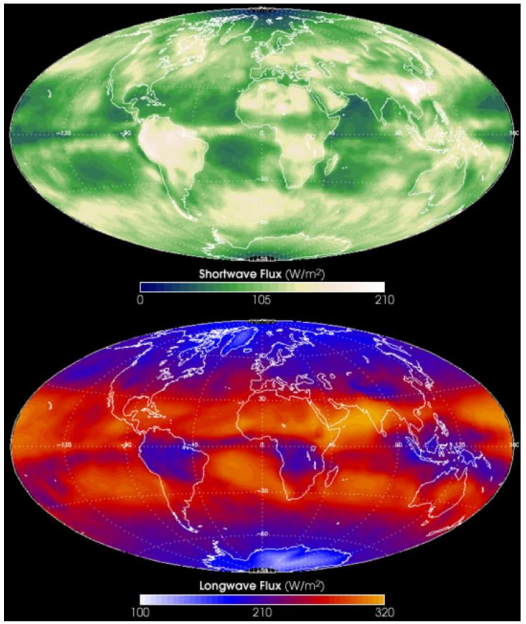


Fig. 1. The global annual mean Earth's energy budget for the Mar 2000 to May 2004 period (W m^{-2}). The broad arrows indicate the schematic flow of energy in proportion to their importance.



Imagery of reflected short wave and emitted long wave radiation acquired by NASA's Clouds and the Earth's radiant Energy System, or CERES, sensors during March 2000

Trenberth et al., 2009

Introduction to Climate Modeling

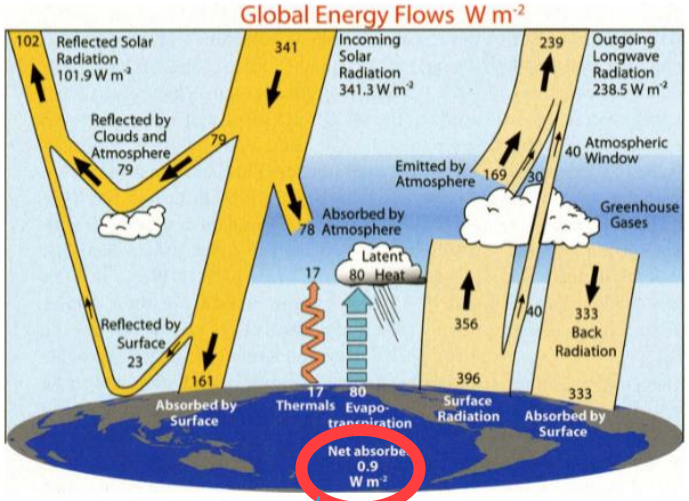
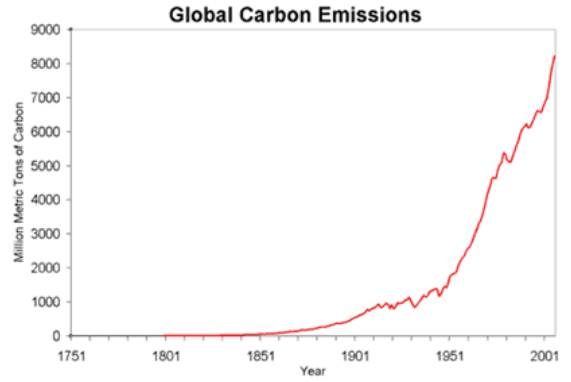
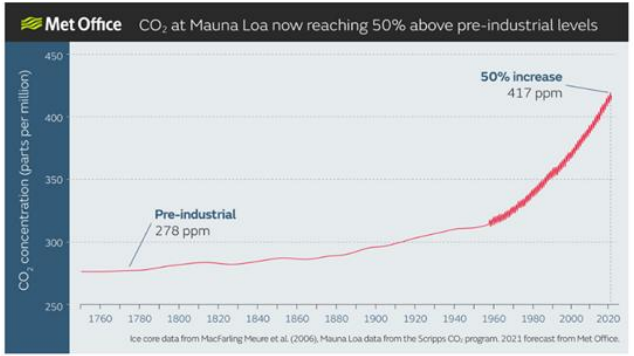


FIG. 1. The global annual mean Earth's energy budget for the Mar 2000 to May 2004 period (W m^{-2}). The broad arrows indicate the schematic flow of energy in proportion to their importance.

Representative Concentration Pathways (RCP):
2.6, 4.5, 6.0, 8.5 W/m^2





Global atmospheric CO2 concentrations from 1700 to 2021. Credit: Met Office.

Trenberth et al., 2009

Introduction to Climate Modeling

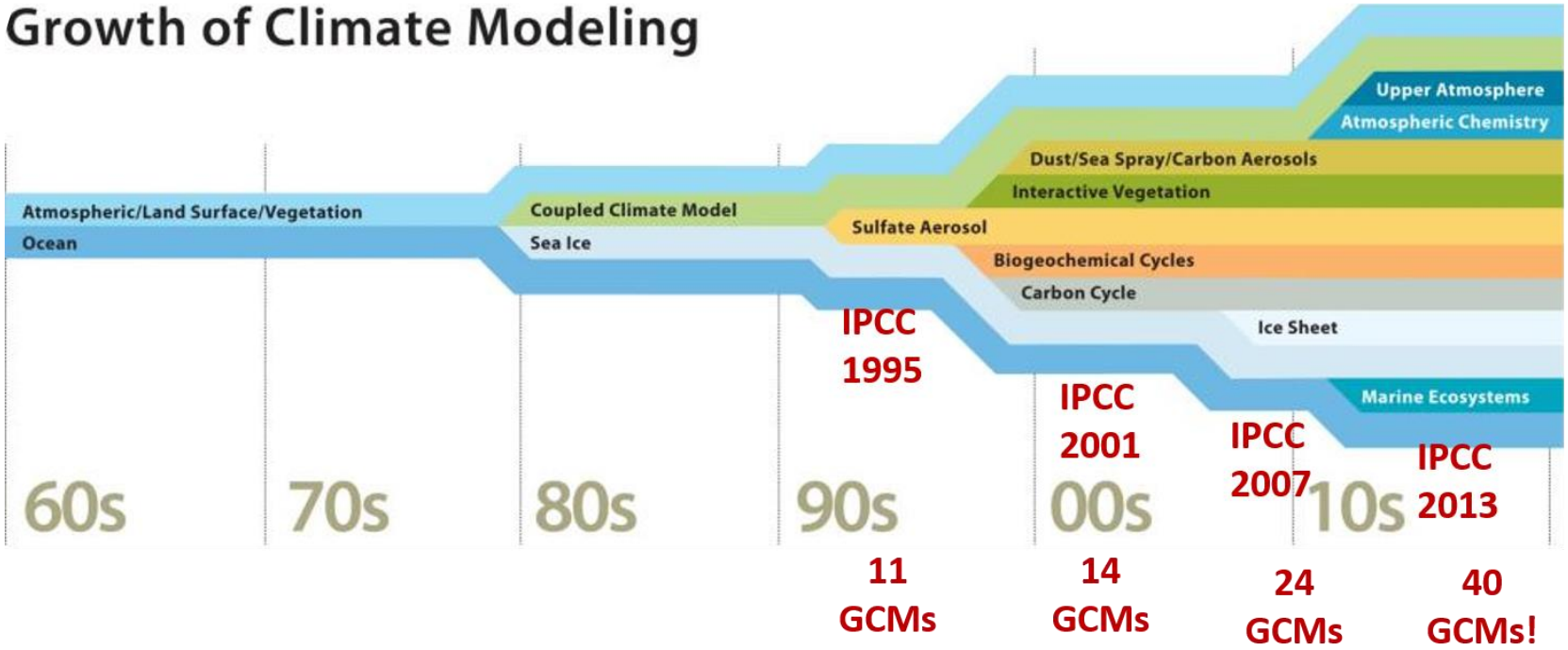
Christopher G. Fletcher. Water Institute-IC3 Summerschool. 2021, Waterloo.

Figure from **meted.ucar.edu**

Mathematical Equations + Parameterization (e.g., topography)

```
!**** DIAGNOSTIC VARIABLES
        MC0(  0:IM*2,0:IM,0:4), &
        MA0(  0:IM*2,0:IM,0:4),      MB0(  0:IM*2,0:IM,0:4), &
        VA0(3,0:IM*2,0:IM,0:4),      VB0(3,0:IM*2,0:IM,0:4), &
     dMCdTADV(  0:IM*2,0:IM,0:4), &
     dVAdTADV(3,0:IM*2,0:IM,0:4), dVBdTADV(3,0:IM*2,0:IM,0:4), &
     dVAdTPGF(3,0:IM*2,0:IM,0:4), dVBdTPGF(3,0:IM*2,0:IM,0:4), &
     MASS(0:1000), AMX(0:1000),AMY(0:1000), AMZ(0:1000),EP(0:1000),EK(0:1000),ET(0:1000),PENS(0:1000), &
     ML1(1000),ML2(1000),MLI(1000), VL1(1000),VL2(1000),VLI(1000), AMZAP(1000,2),EKAP(1000,2)
     EndModule ICOS


     Program MAIN
     Use ICOS
     Implicit None
     Integer :: I,J,K, NARGS
     Real*8  :: DTFS,DTLF, VARH, &
        HCX(0:IM*2,0:IM,0:4), MAX(0:IM*2,0:IM,0:4),MBX(0:IM*2,0:IM,0:4), VAX(3,0:IM*2,0:IM,0:4),VBX(3,0:IM*2,0:IM,0:4), &
        HCO(0:IM*2,0:IM,0:4), HAO(0:IM*2,0:IM,0:4),MBO(0:IM*2,0:IM,0:4), VAO(3,0:IM*2,0:IM,0:4),VBO(3,0:IM*2,0:IM,0:4)
     Real*8 :: &
        dMC(0:IM*2,0:IM,0:4), dVA(3,0:IM*2,0:IM,0:4),dVB(3,0:IM*2,0:IM,0:4)  !  acceleration
     Character*80 :: ARG,FILOUT

!**** Collect command line argument
     NARGS = IArgC()
     If (NARGS == 0)  GoTo 800
     Call GetArg (1,ARG)  ;  Read (ARG,*) NDAYS
     Write (0,*) 'IM,DT,DTSRC,SDAY=',IM,DT,DT*NDYNS,DT*NDYNS*NSRCS

!**** Initialize variables
     Call GEOMETRY
     Call INPUT
     Call MCtoMAB (MC, MA,MB)
     MC0(  :,:,:) = MC(  :,:,:)  ;  MA0(  :,:,:) = MA(:,:,:)  ;  MB0(:,:,:) = MB(:,:,:)
     VA0(:,:,:,:) = VA(:,:,:,:)  ;  VB0(:,:,:,:) = VB(:,:,:,:)

     ZTC(:,:,:) = SPVOL*MC(:,:,:) + ZSC(:,:,:)
     Call WRITEC  (ZTC(0,0,0),MM,1d3,'(ZTC0 - MM) * 1d3 : initial altitude of fluid top at grid cell centers')
     VAX(3,:,:,:) =  VA(3,:,:,:) * zCOSA(3,:,:,:)
     VBX(3,:,:,:) =  VB(3,:,:,:) * zCOSB(3,:,:,:)
     VAX(1,:,:,:) = (VA(1,:,:,:)*PA(2,:,:,:) - VA(2,:,:,:)*PA(1,:,:,:)) * zCOSA(3,:,:,:)
     VBX(1,:,:,:) = (VB(1,:,:,:)*PB(2,:,:,:) - VB(2,:,:,:)*PB(1,:,:,:)) * zCOSB(3,:,:,:)
     Call WRITEAB (VAX(3,0,0,0),VBX(3,0,0,0),1d3,'W0 * 1d3 : initial eastward velocity at points A and B')
     Call WRITEAB (VAX(1,0,0,0),VBX(1,0,0,0),1d3,'W0 * 1d3 : initial northward velocity at points A and B')
     Call DIAGC (0)
     Write (6,904) 0, MASS(0), AMX(0), AMZ(0), Nint(EP(0),8), Nint(EK(0),8), Nint(ET(0),8), Nint(1000*PENS(0))
     NDAY = 0  ;  NSRC = 0  ;  NDYN = 0
     DTLF = DT*2  ;  If (NDAYS == 0)  GoTo 500  !  compare initial differential results with numerical scheme
```

A Brief History of Climate Modeling

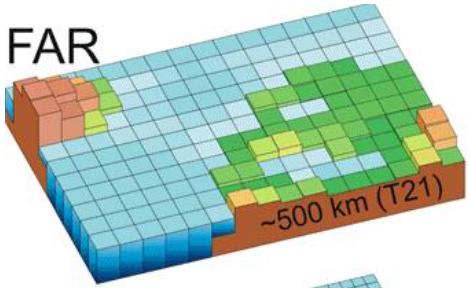


Feedback effects (e.g., polar vortex)

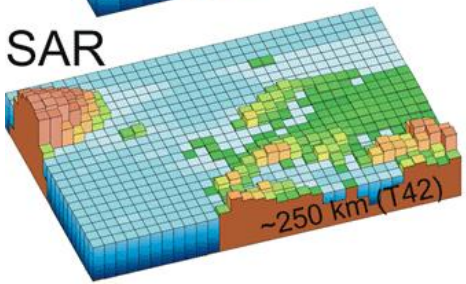
Convective Processes (E.g., localized extreme rainfall)

As Global Climate Models have Advanced, so has their Spatial Resolution…

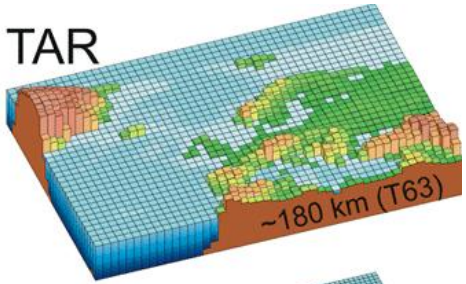
IPCC (1990)



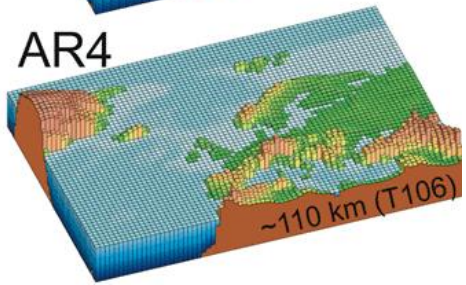
IPCC (1995)

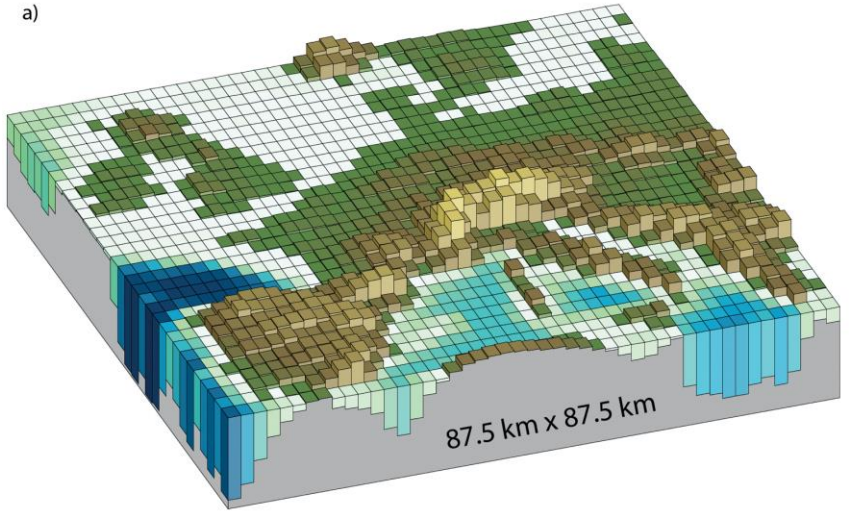


IPCC (2001)



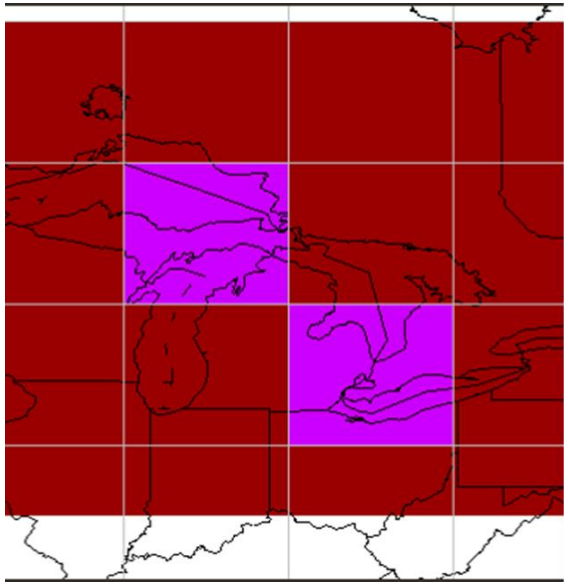
IPCC (2007)



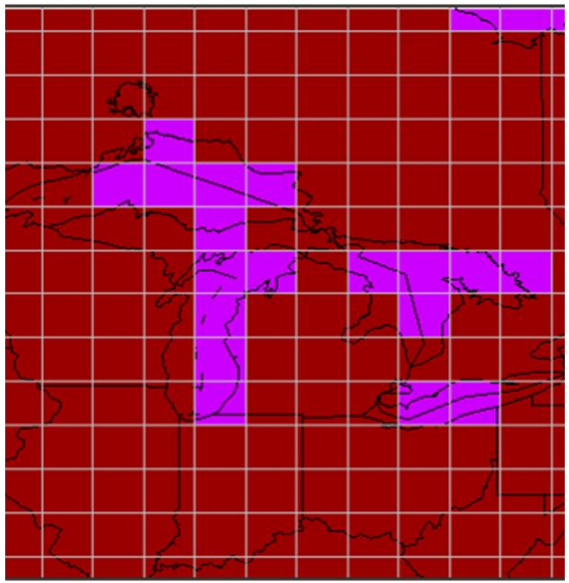


IPCC (2013) – AR5

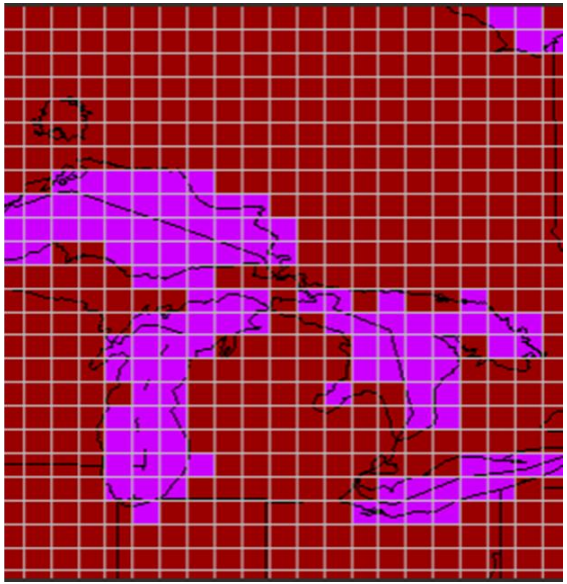
Spatial Resolution Matters particularly in the Great Lakes Basin…



IPCC 2013 GCM

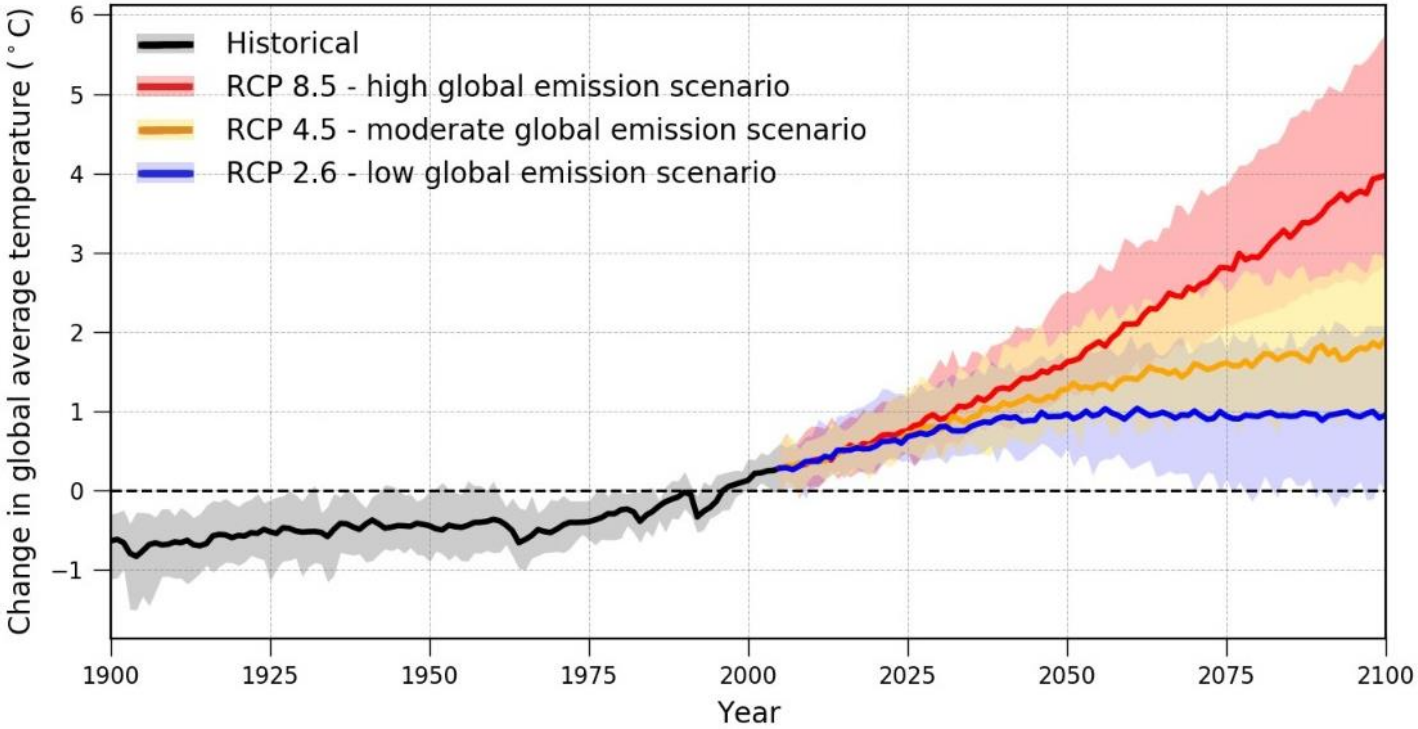


Regional Climate Model (50 x 50km)



Regional Climate Model (25 x 25km)

Climate Change Scenarios



Approach

Obtain Data

Collect Historical Data

Future time-series for each grid cell

Quality Control & Infilling Gaps

Historical Characterization

Use baseline (1971-2000)

Spatial, seasonal, long term temporal trend analyses

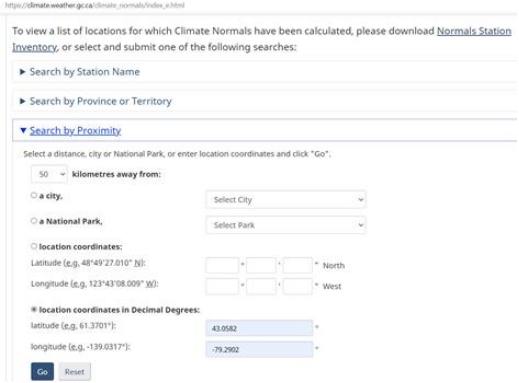
Future Analysis

Bias Correction

Determine anomalies

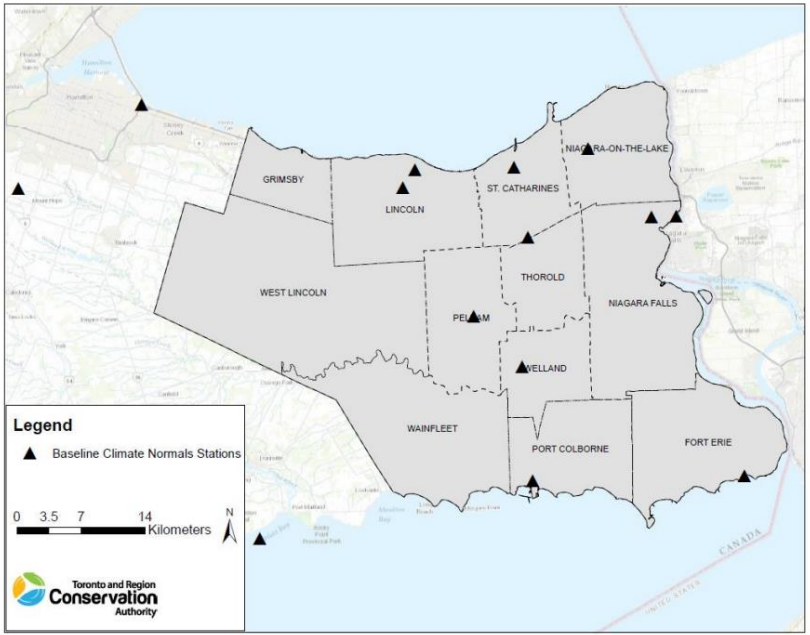
Spatial, seasonal, long term temporal trend analyses

Historical Data Accessed for Niagara Region



Station No.	Station Name	Longitude	Latitude
1	FORT ERIE	78.97◦ W	42.88◦ N
2	NIAGARA FALLS NPCSH	79.05 ◦ W	43.13◦ N
3	NIAGARA FALLS	79.08 ◦ W	43.13◦ N
4	PORT COLBORNE	79.25 ◦ W	42.88◦ N
5	PORT DALHOUSIE	79.27 ◦ W	43.18◦ N
6	RIDGEVILLE	79.33 ◦ W	43.04◦ N
7	ST CATHARINES A	79.17 ◦ W	43.20◦ N
8	ST CATHARINES POWER GLEN	79.25 ◦ W	43.12◦ N
9	VINELAND RITTENHOUSE	79.42 ◦ W	43.17◦ N
10	VINELAND STATION	79.40 ◦ W	43.18◦ N
11	WELLAND	79.26 ◦ W	42.99◦ N
12	HAMILTON A	79.93 ◦ W	43.17◦ N

Baseline Climate Data from Environment Canada Meteorological Stations



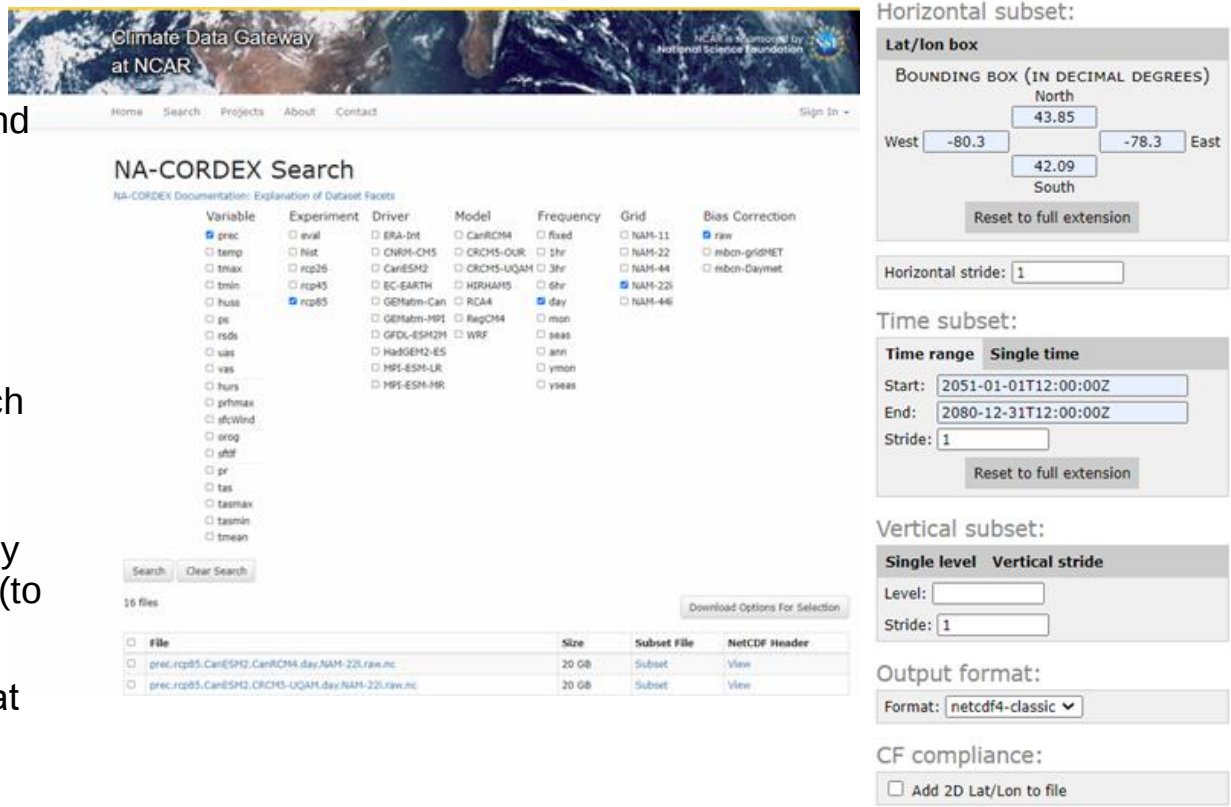
Extracting Future Climate Data

Downloaded daily temperature and precipitation data for:

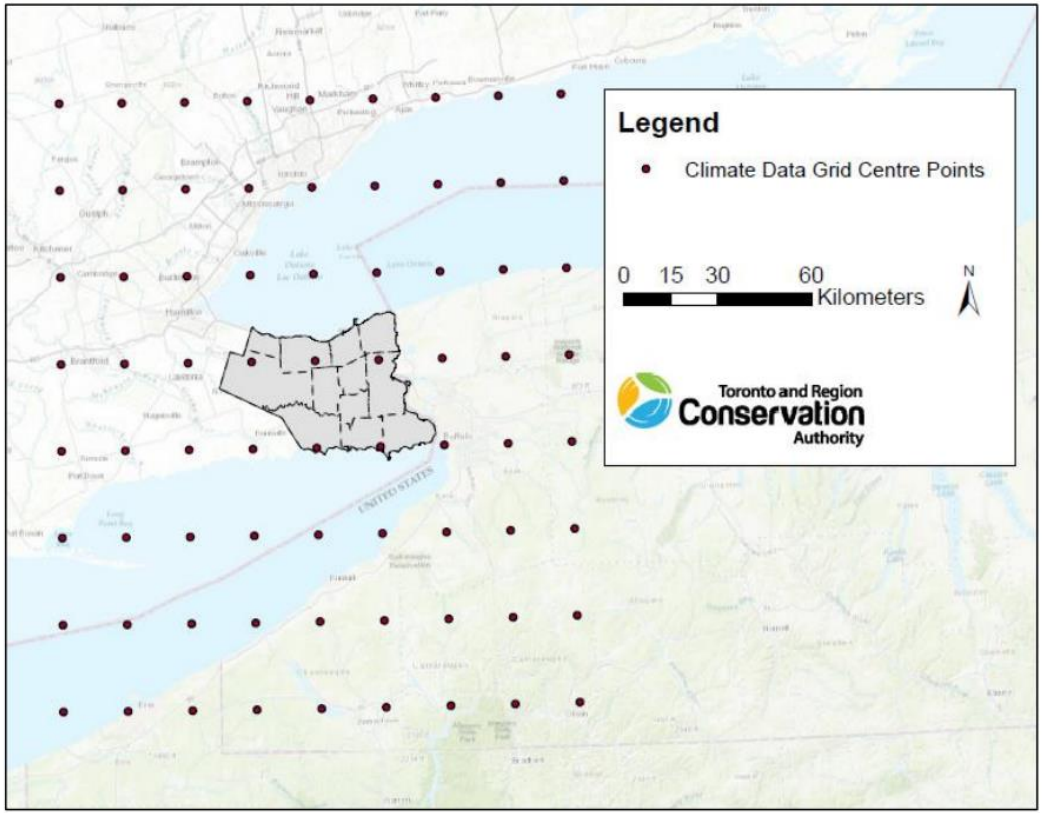
- RCP 4.5 and RCP 8.5 Scenarios
- Up until 2080

16 Regional Climate Models which are:

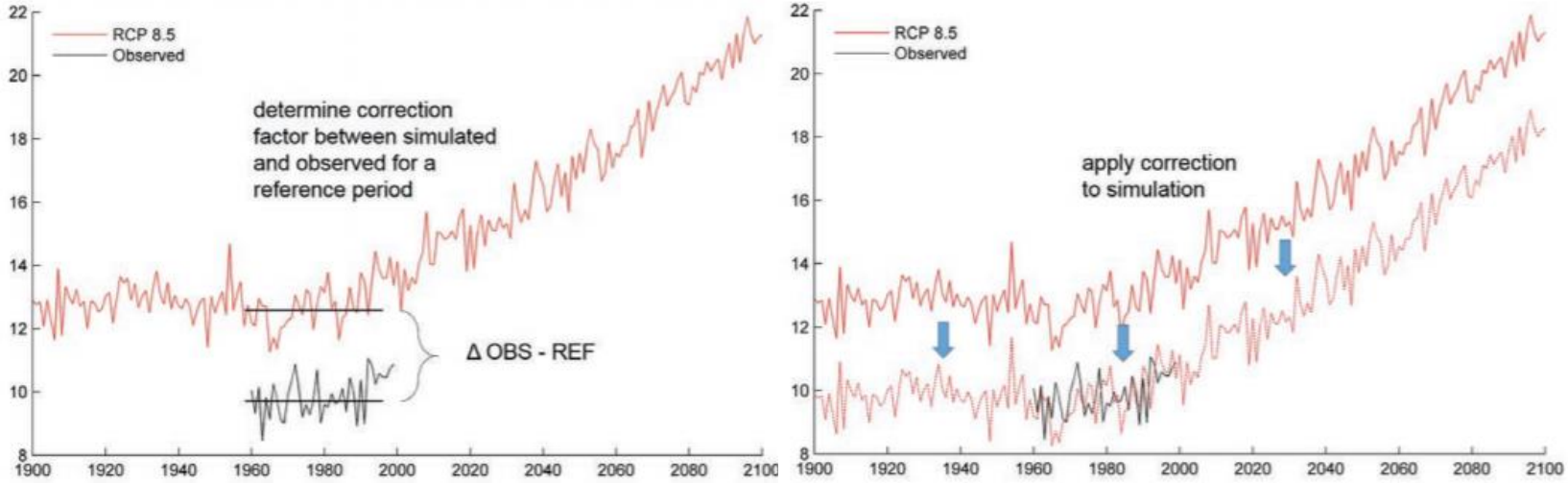
- Dynamically-downscaled (physics-based) models run by differing boundary conditions (to account for uncertainties)
- “Raw” climate model output at 25 x 25 km grid cells



NA-CORDEX Data



Conducting Bias Correction



Climate Parameters

Direct Model Output (4)

- Mean Air Temperature
- Max Air Temperature
- Min Air Temperature
- Total Precipitation

Inferred or Calculated (52)

- All Threshold-based Parameters
- Extreme Precipitation
- Growing Season
- Dry Conditions
- Freeze-Thaw
- Ice Potential

Model Confidence Level

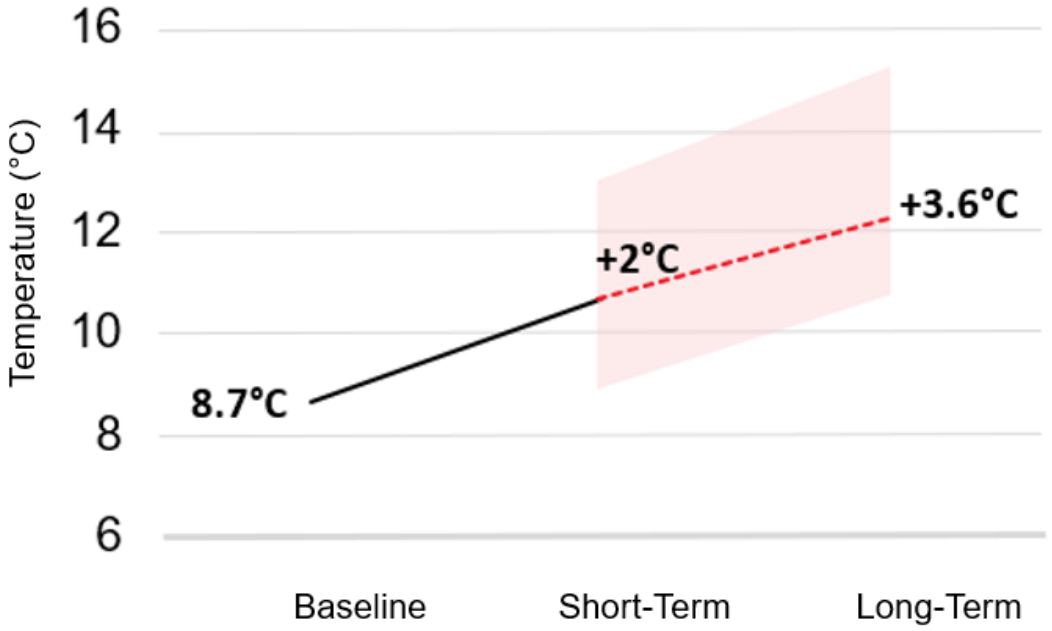
To assess the robustness of the future projections, the agreement in change direction between models and the strength of the change signal from the baseline values are assessed

- **The change direction agreement** evaluates how many models agree on the direction of change for each parameter from baseline to future periods

- **Change signal** compares the magnitude of change between baseline and future climate periods to the variability of means between models in the future period

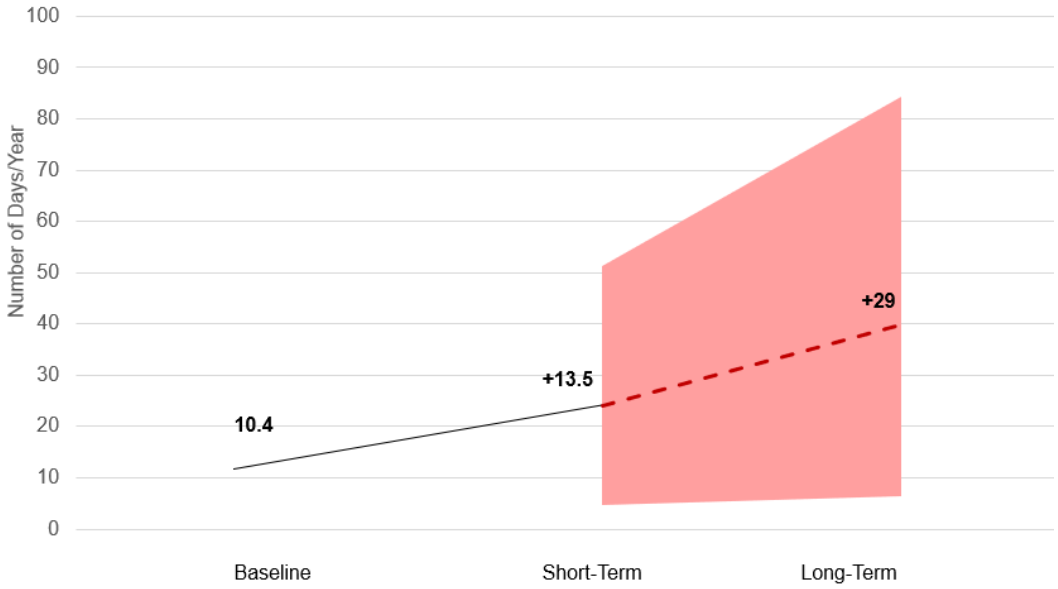
Regional Climate Projections Under RCP8.5 Scenario

Mean Annual Daily Air Temperature



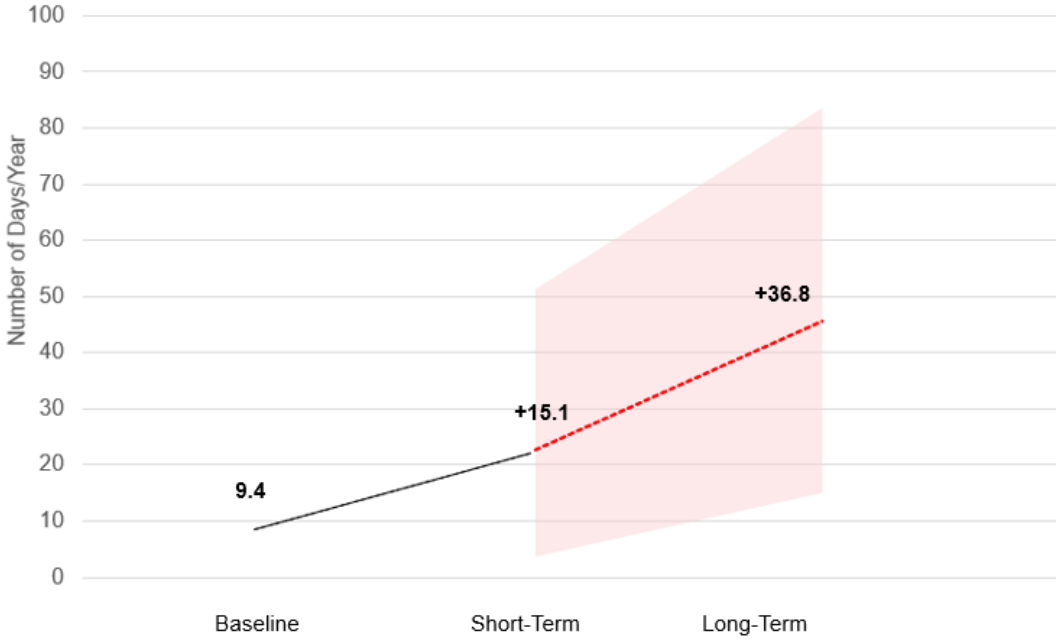
Change Direction Agreement	Change Signal
High	High

Extreme Heat Days: Daily Max Temperature > 30˚C



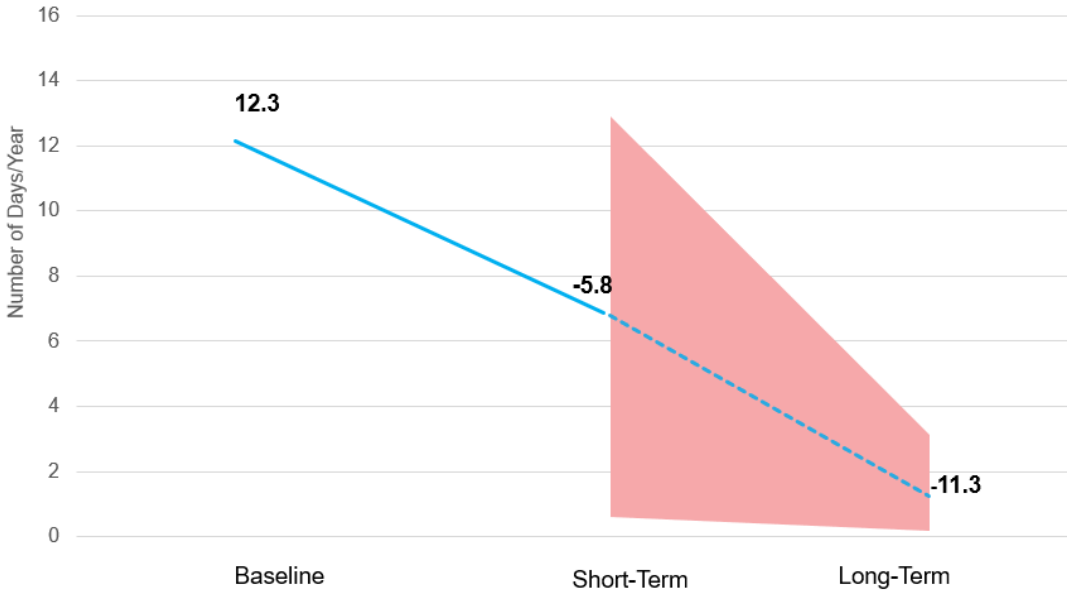
Change Direction Agreement	Change Signal
Medium	Medium

Tropical Nights: Daily Minimum Temp > 20 ˚C



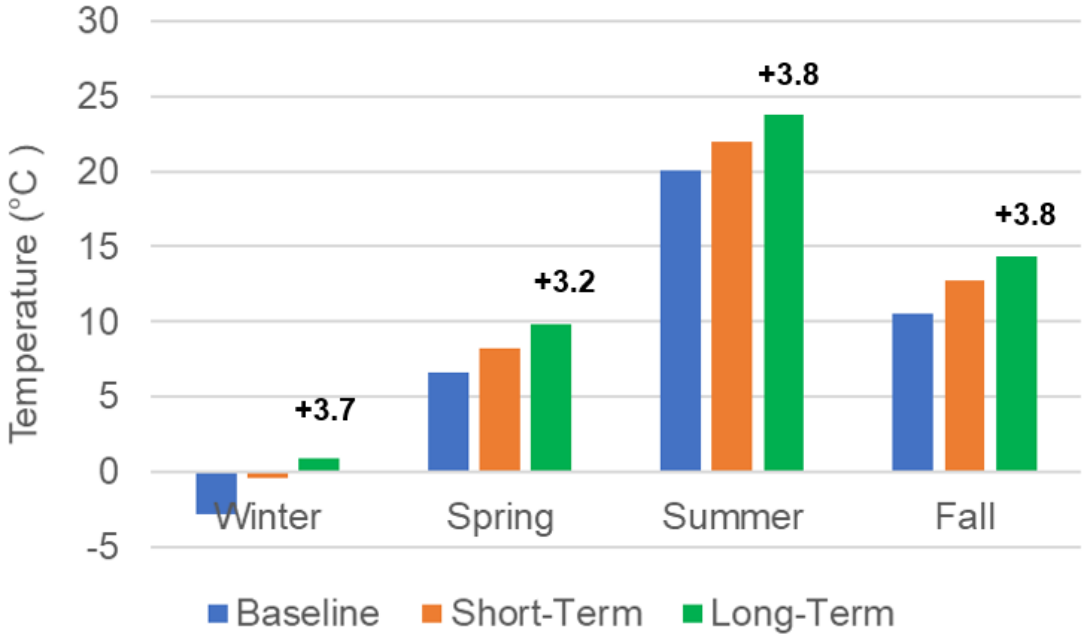
Change Direction Agreement	Change Signal
High	Medium

Extreme Cold Days: Daily Minimum Temp < -15˚C



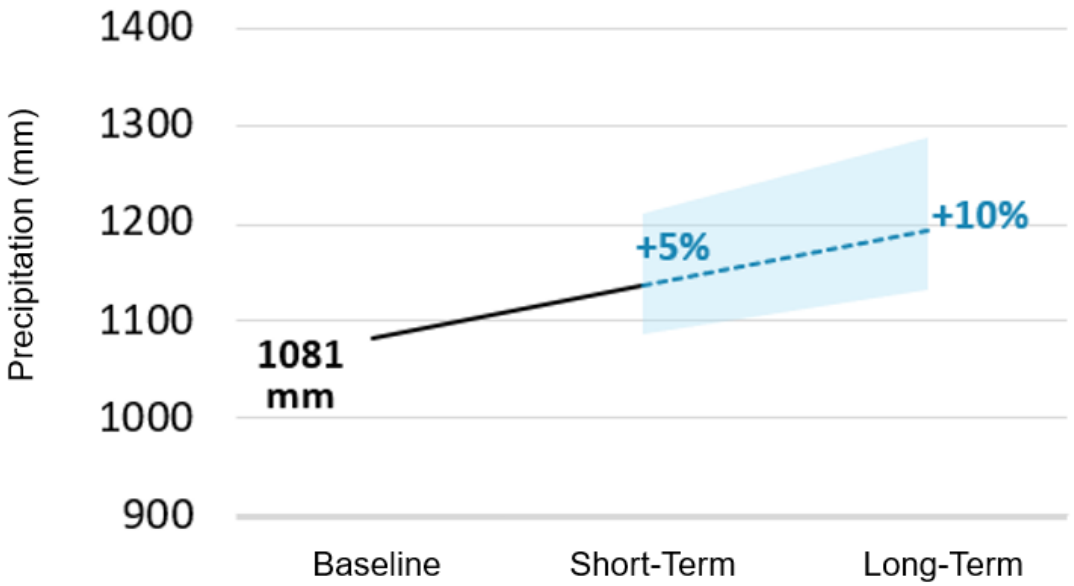
Change Direction Agreement	Change Signal
High	High

Mean Seasonal Air Temperature



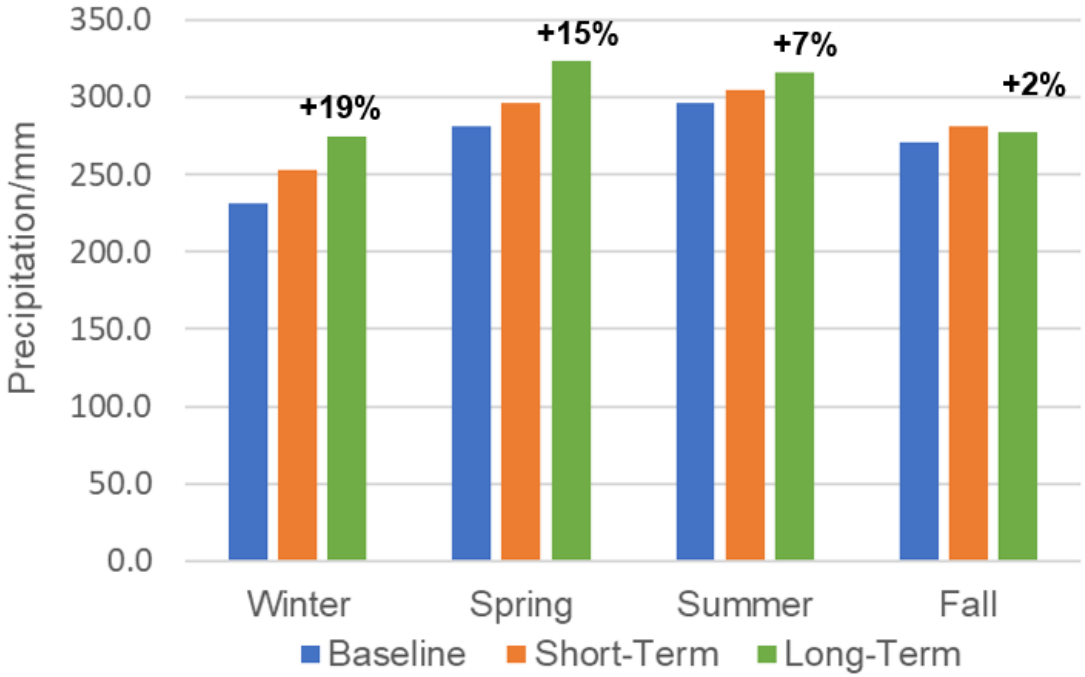
Season	Change Direction Agreement	Change Signal
Winter	High	Medium
Spring	High	Medium
Summer	High	Medium
Fall	High	Medium

Mean Annual Total Precipitation



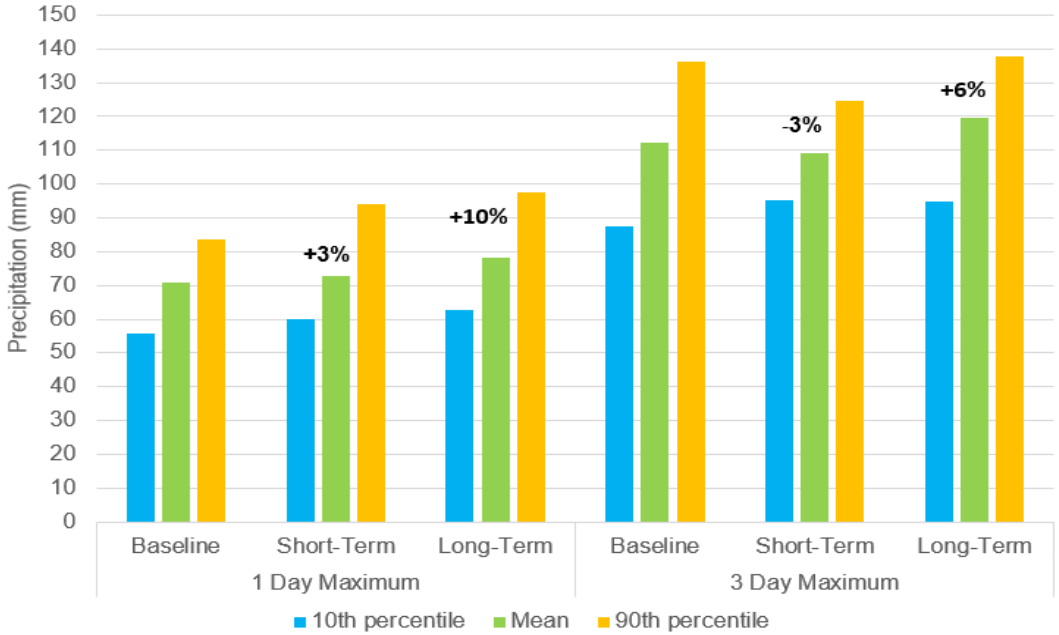
Change Direction Agreement	Change Signal
High	Medium

Mean Seasonal Total Precipitation



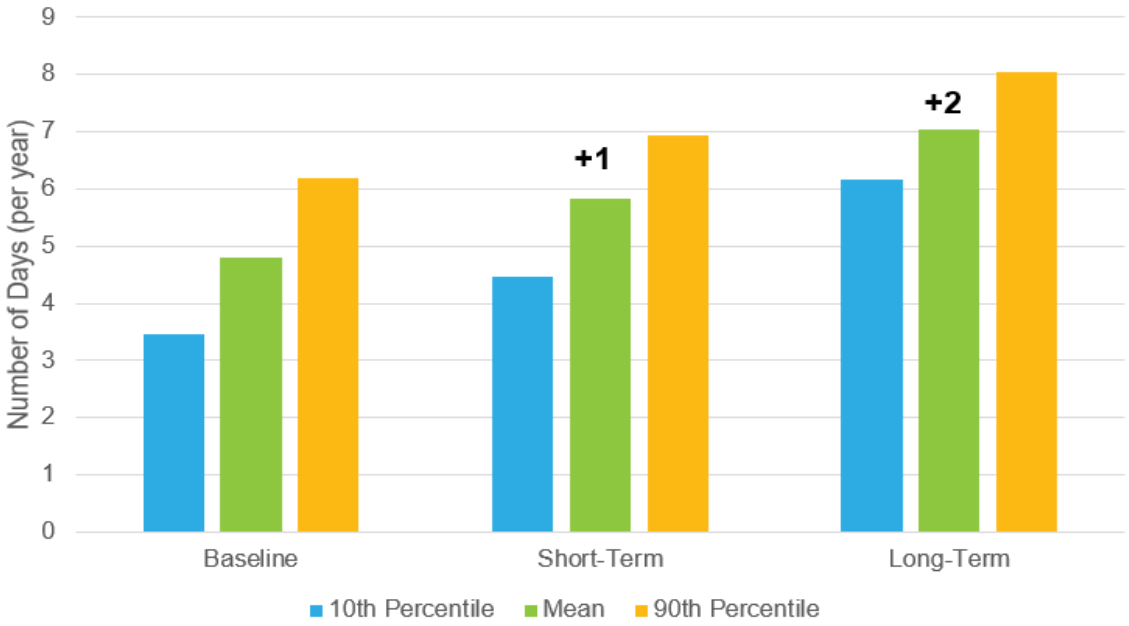
Season	Change Direction Agreement	Change Signal
Winter	Medium	Medium
Spring	High	Medium
Summer	Low	Low
Fall	Low	Low

Extreme Precipitation: 1-Day and 3-Day Maximum Precipitation



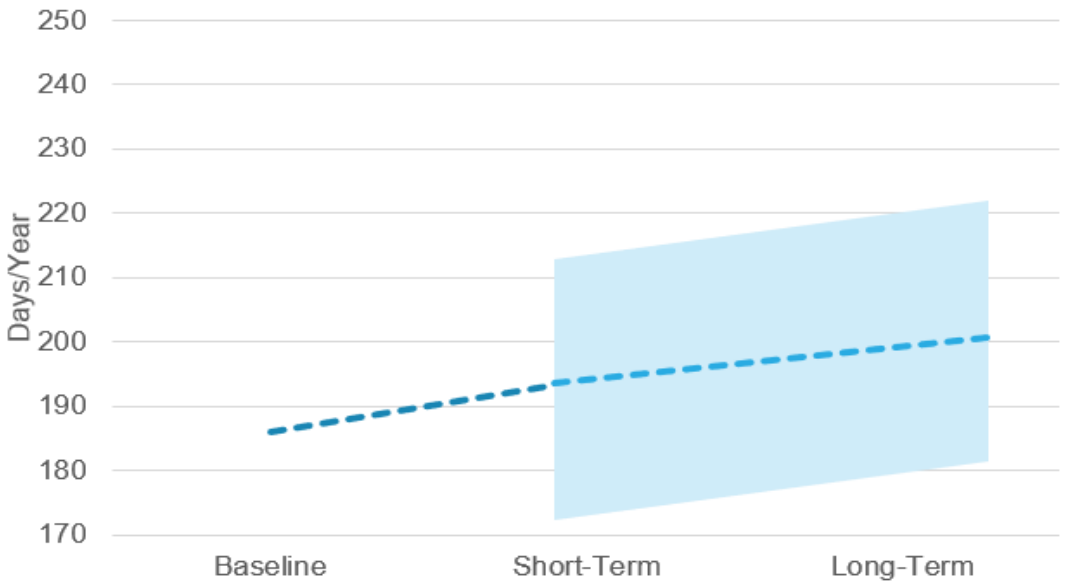
Change Direction Agreement	Change Signal
Low	Low

Extreme Precipitation: Daily Precipitation > 25mm



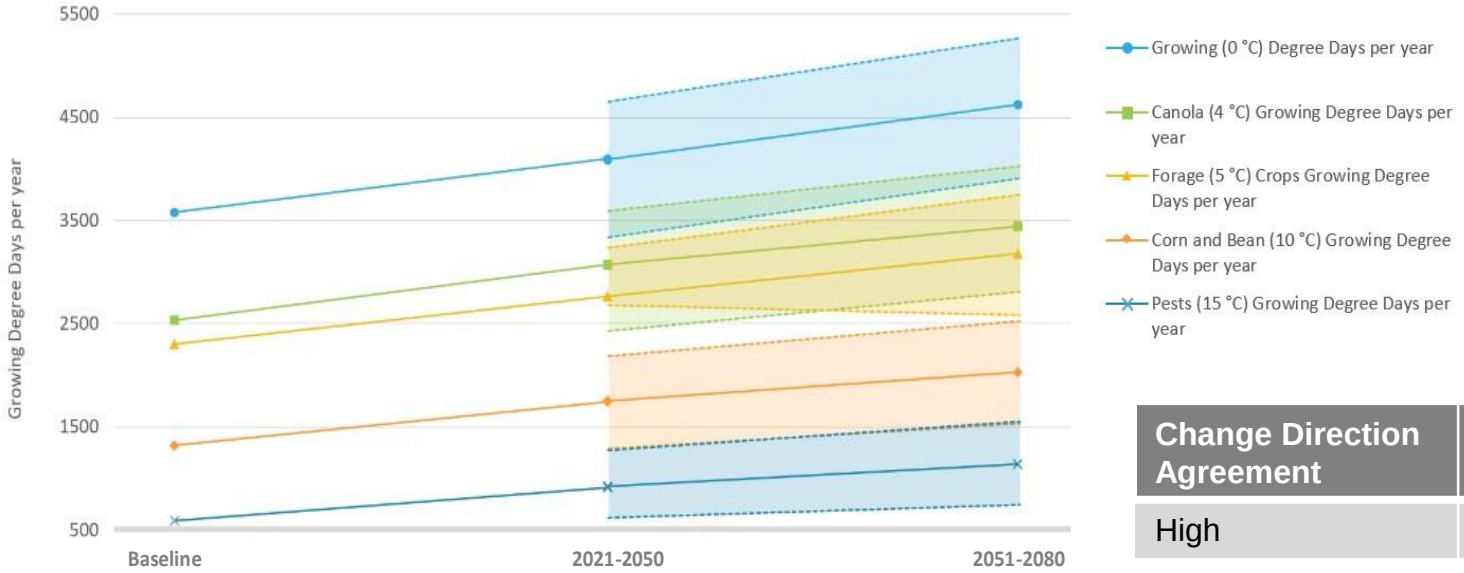
Change Direction Agreement	Change Signal
High	High

Growing Season Length



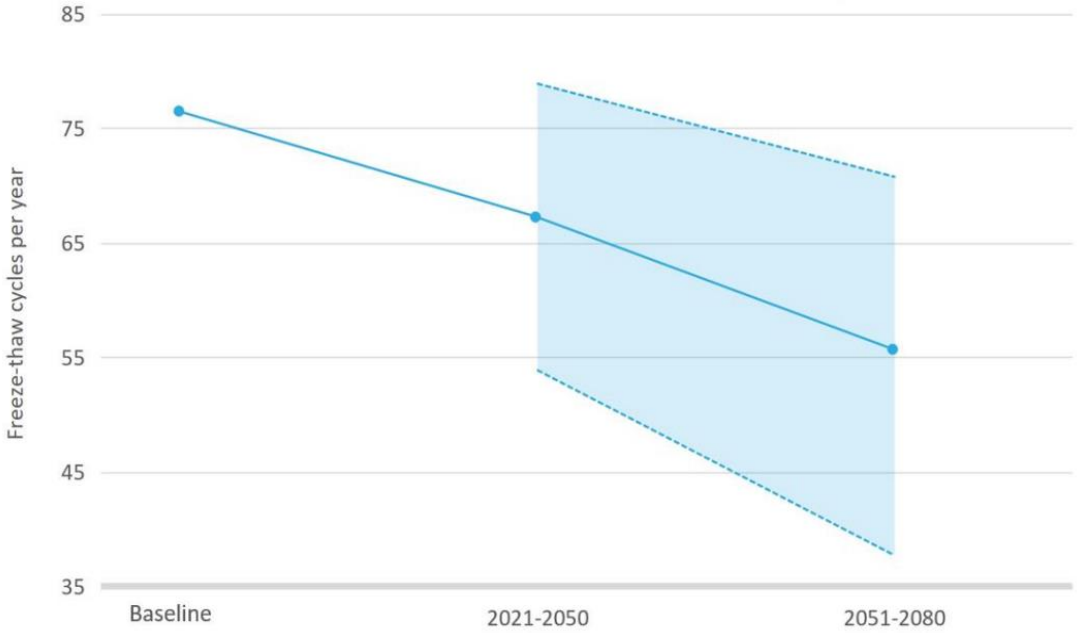
Change Direction Agreement	Change Signal
Medium	High

Annual Growing Degree Days



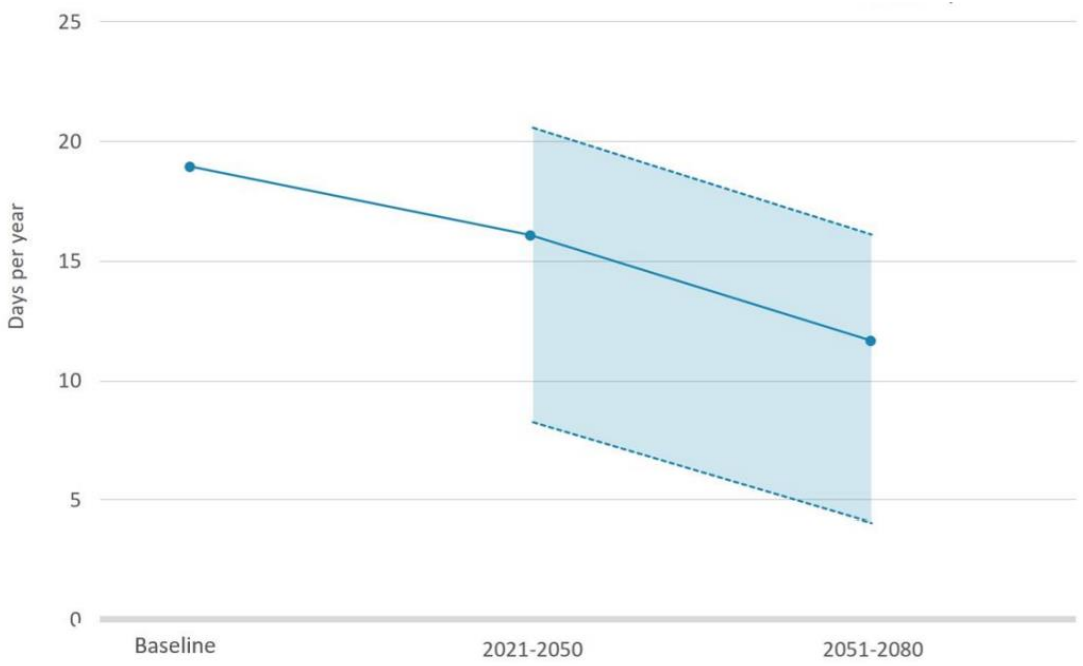
Change Direction Agreement	Change Signal
High	Medium

Freeze-Thaw Cycles: Daily Min Temperature Below -1°C and Max Temperature Above 0°C



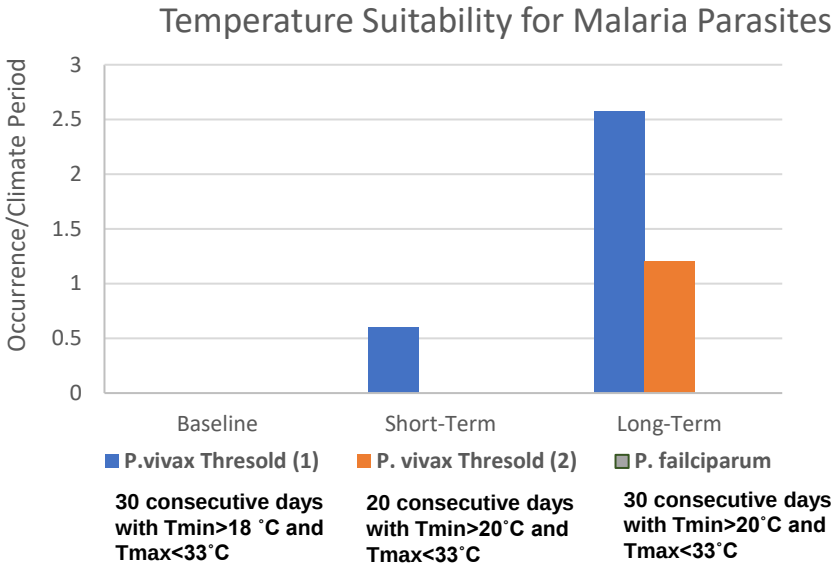
Change Direction Agreement	Change Signal
High	Medium

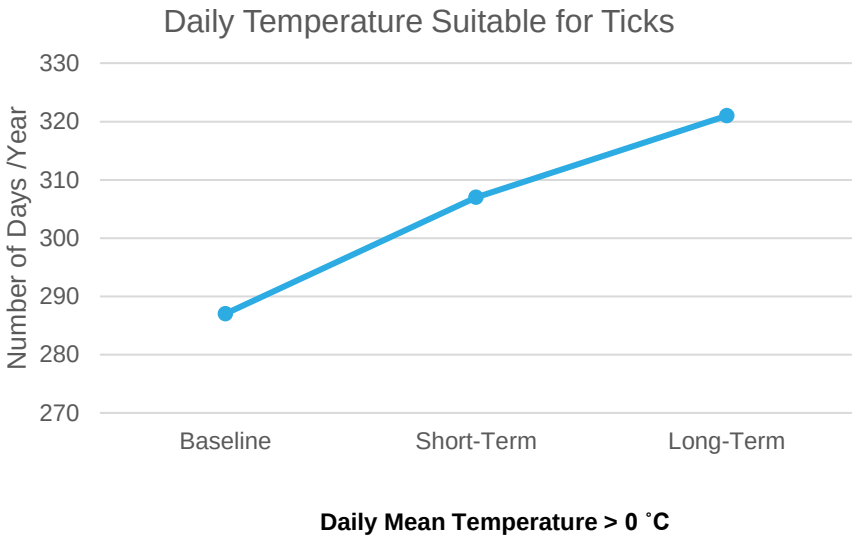
Ice Potentials: Daily Min Temperature < -2˚C, Max Temperature < 2˚C, and Precipitation > 1 mm



Change Direction Agreement	Change Signal
High	Medium

Public Health Variables



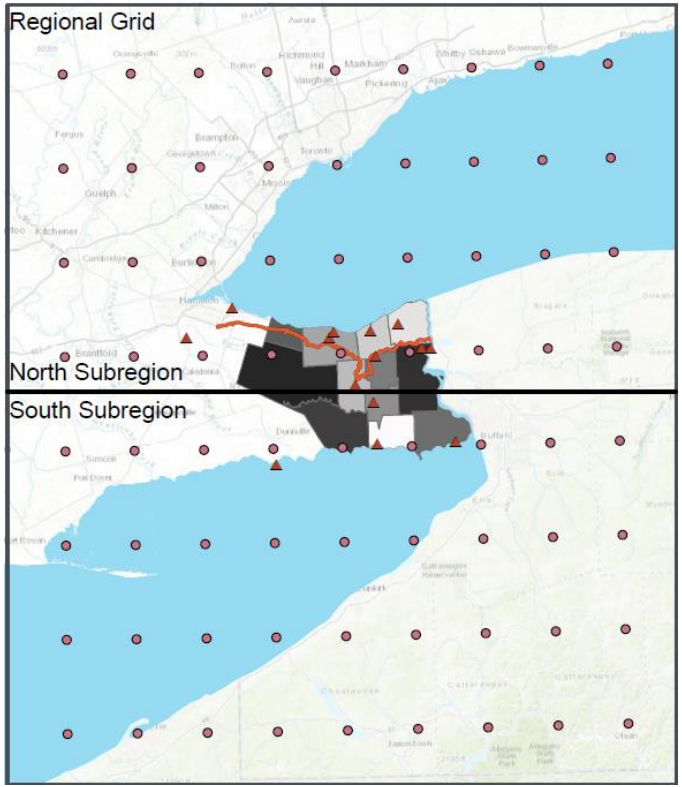


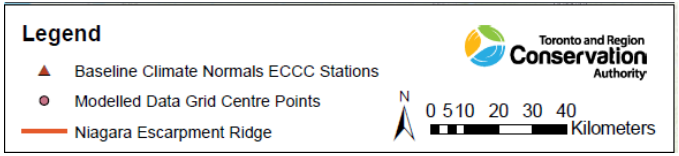
Change Direction Agreement	Change Signal
Low	Low

Change Direction Agreement	Change Signal
High	Medium

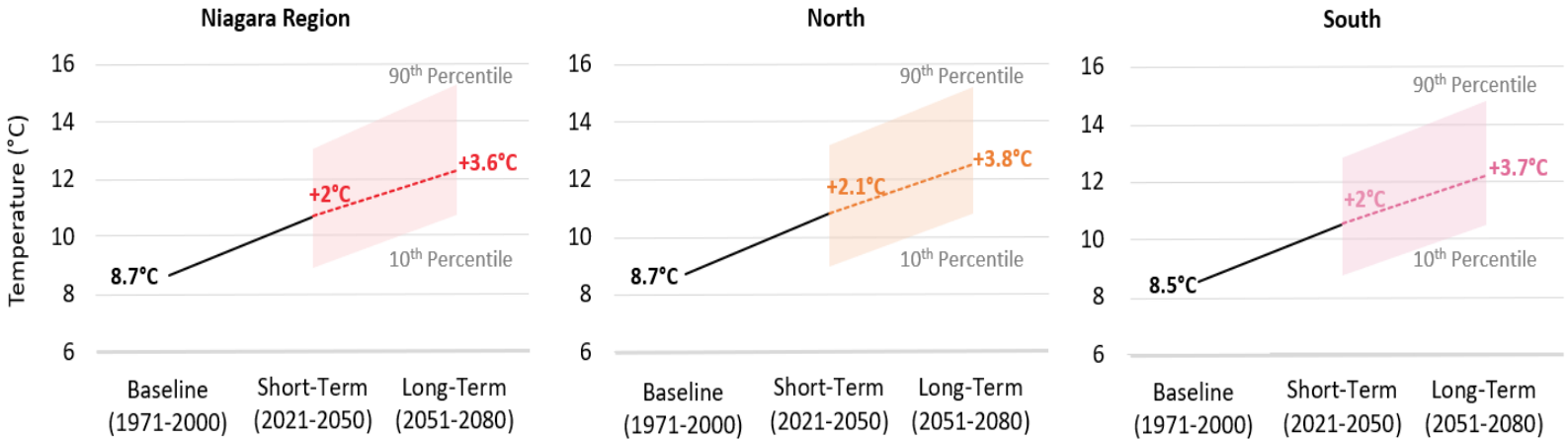
Comparison Between Regional and Subregional Climate Projections Under RCP 8.5 Scenario

Subregional Grid Cells

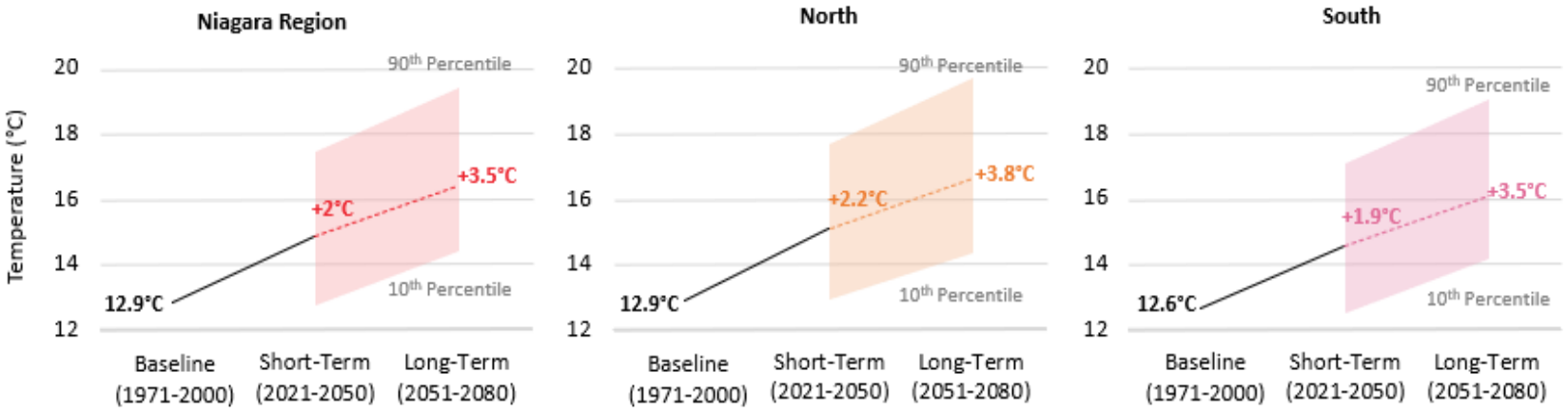




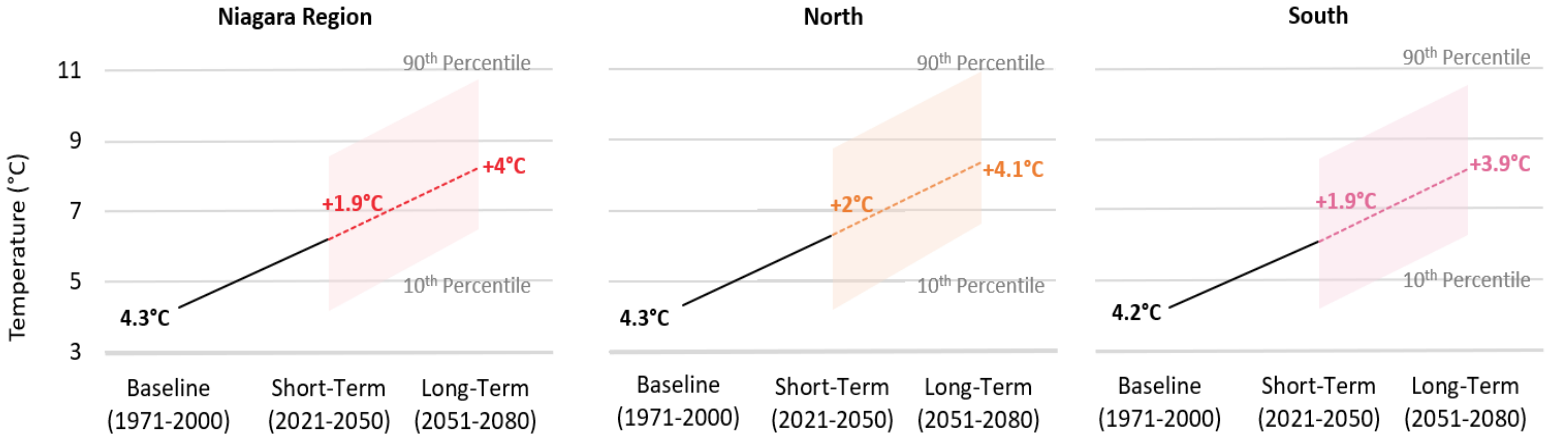
Mean Annual Daily Temperature Between Regional And Subregional Analysis



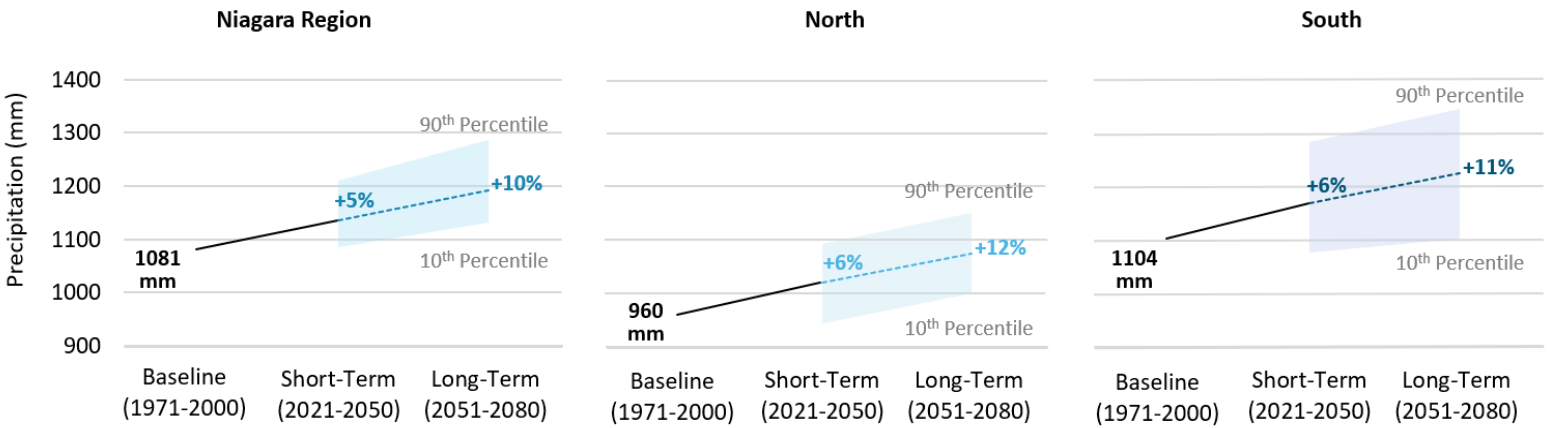
Mean Maximum Daily Temperature Between Regional And Subregional Analysis



Mean Minimum Daily Temperature Between Regional And Subregional Analysis



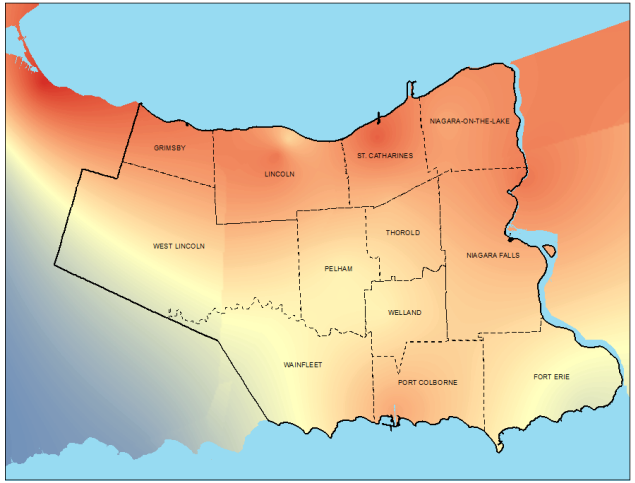
Mean Annual Precipitation Between Regional And Subregional Analysis



Spatial Analysis Under RCP 8.5 Climate Scenario

Average Annual Daily Mean Temperature (˚C)

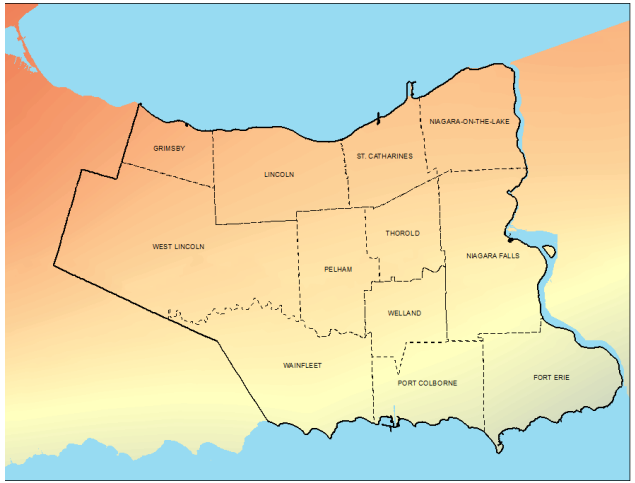
a) 1971-2000



High : 9.3

Low : 7.6

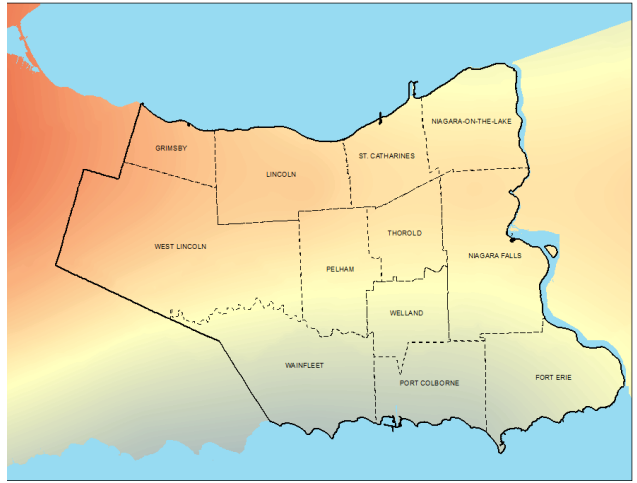
b) 2021-2050



High : 10.9

Low : 10.5

c) 2051-2080

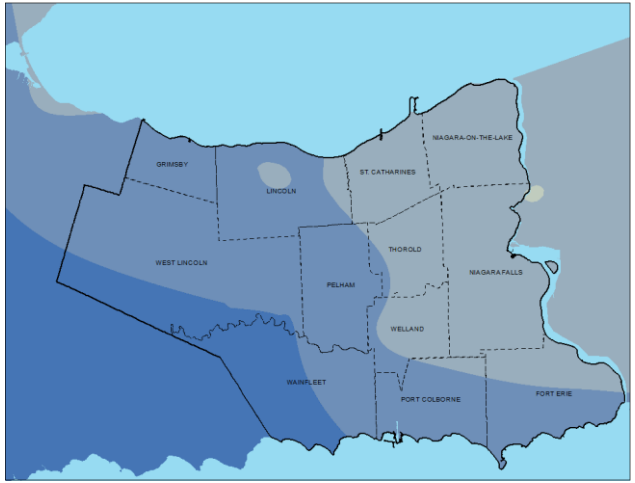


High : 12.5

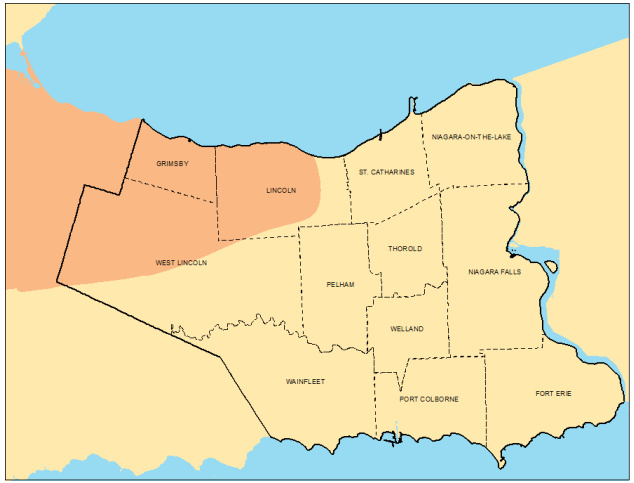
Low : 12.0

Average Annual Daily Max Temperature (˚C)

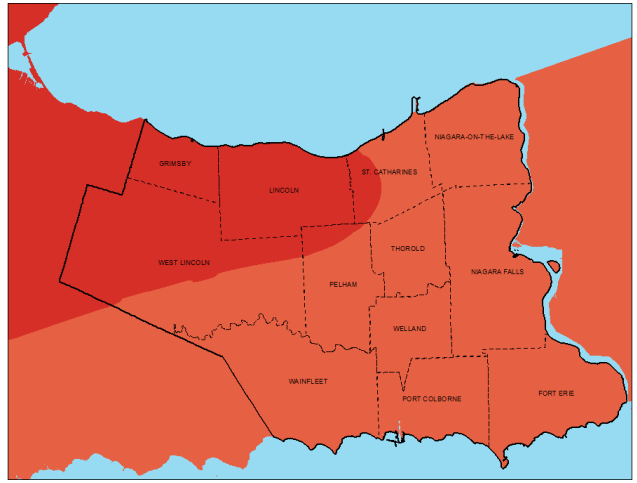
a) 1971-2000 (12-13.5 ˚C)

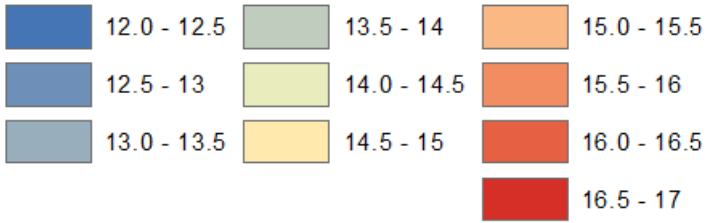


b) 2021-2050 (14.5 – 15.5 ˚C)



c) 2051-2080 (16 -17 ˚C)





1971-2000 to 2021-2050: 1 - 3.5˚C increase

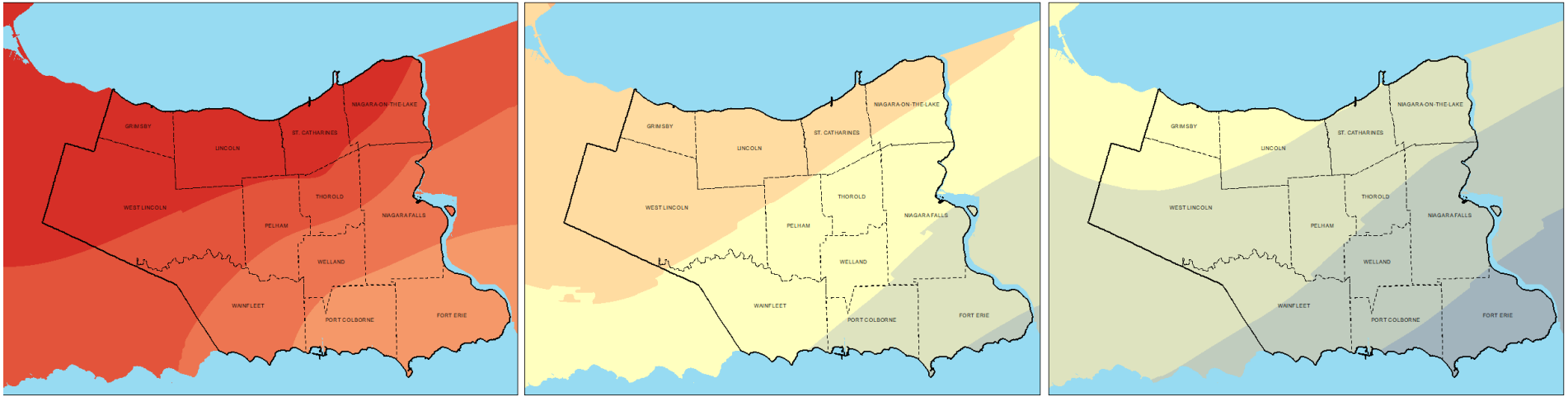
1971-2000 to 2051-2080: 2.5 - 5˚C increase

Average Annual Daily Mean Precipitation (mm)

a) 1971-2000

b) 2021-2050

c) 2051-2080



2.4 - 2.5	2.7 - 2.8	3.0 - 3.1	3.3 - 3.4	3.6 - 3.7
2.5 - 2.6	2.8 - 2.9	3.1 - 3.2	3.4 - 3.5	
2.6 - 2.7	2.9 - 3.0	3.2 - 3.3	3.5 - 3.6	

1971-2000: 2.4 - 2.8 mm
2021-2050: 2.9 - 3.3 mm
2051-2080: 3.0 - 3.4 mm

A Rapid Comparison Between TRCA and Niagara Adapts Regional Climate Projections

	TRCA	SCCCAP
Data Source(s)	NA-CORDEX (the North American component of the Coordinated al Downscaling Experiment)	Climatedata.ca
Baseline Period	1971-2000	1976-2005
Future Periods	2021-2050 and 2051-2080	2050 and 2100 (one year only)
Climate Stations	12 Climate Stations	It is unclear which stations or how many contributed to St. Catharines projections
GCMs or RCMs?	Ensemble of RCMs	Ensemble of GCMs from CMIP5 (the Coupled Model Intercomparison Project)
Number of Climate Models	16 climate models	24 climate models
Climate Scenarios	RCP 4.5 and 8.5	RCP 8.5
Bias Correction Method	Delta approach where delta = difference between observed and modelled baseline values; one delta is produced for each model for all climate variables	Statistical downscaling (Bias Correction with Constructed Analogues and Quantile mapping, Version 2; BCCAQv2)
Output Scale	~25 km x 25 km	~10 km x 6 km
Consideration for the influence of the Great Lakes	Part of the model selection criteria so all models include some representation of the Great Lakes	n/a

A Rapid Comparison Between TRCA and Niagara Adapts Regional Climate Projections

Variable	TRCA (2021 2050)			SCCAP (2050)
	10th Percentile	Mean	90th Percentile	Mean
Mean Annual Air Temperature	8.9	10.7	13.0	9
Mean Winter Temperature	-3.5	-0.4	1.9	0
Mean Spring Temperature	6.4	8.2	10.4	9
Mean Summer Temperature	20.2	22.0	24.2	23
Mean Fall Temperature	10.9	12.7	15.4	14
Mean Annual Maximum Daily Air Temperature	12.7	14.9	17.4	17
Mean Annual Minimum Daily Air Temperature	4.2	6.2	8.5	8
Mean Annual Total Precipitation	1086.0	1135.0	1209.1	1018
Mean Winter Total Precipitation	214.7	253.0	288.1	208
Mean Spring Total Precipitation	256.0	296.2	324.2	233
Mean Summer Total Precipitation	246.8	305.0	340.8	210
Mean Fall Total Precipitation	244.5	280.8	317.5	223

Conclusions

It can be expected that by the 2080s under RCP 8.5 Niagara Region will be:

- Warmer (~3.5˚C increase)
- Wetter (~10%increase)
- More intense storms (~10% increase in 1-day maximum precipitation)
- Opportunities for agricultural crops to thrive (increase in growing degree days by 10% to 20%), however, risk of pests will be higher by ~30%

Limitations of the Study

- There are more suitable bias correction methods for precipitation datasets (quantile mapping)
- Baseline results are derived from modeled data
- Areal extents of the study area and number of grid cells used have an impact on the results

Discussion Questions

1. What are your impressions of the data?
2. How is climate data being used now?
3. How can climate data be integrated into future projects?
4. Are there additional climate parameters/products of interest?

Thank You!

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